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Regime Shifts and Recruitment in the Western and Central Pacific Ocean

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Introduction

The term "regime shift" has frequently been used rather loosely in marine science literature. "Regime shift" is broadly understood to mean a well-defined and rapid transition between two relatively stable states. Its usage is clearest when it is context-dependent, e.g., "climate," "ecosystem," or "recruitment" regime shifts for specified areas, systems, or species.

There is an underlying assumption of cause and effect between climate and ocean ecosystem variability. Climate variability is assumed to lead to changes in recruitment and biomass of fish stocks through its effects on ocean variables such as temperature and primary productivity.

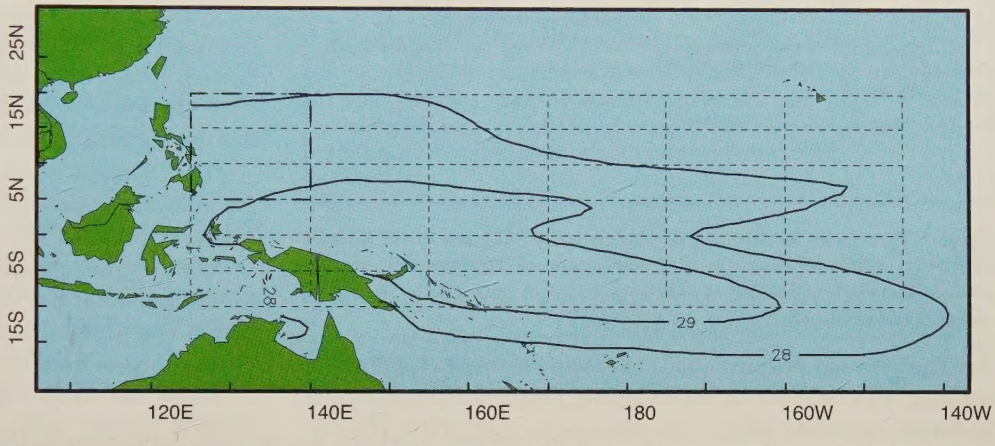

Figure 1. Average position of the Western Pacific Warm Pool over 1948–2004, as delimited by the 28°C and 29°C isotherms, the areas considered (grid), and the final area selected (top left) in the GLM.

The purpose of this study was not to mechanistically describe the causal relationships leading to regime shifts but rather to examine the statistical evidence for them. Such an examination would allow us to better understand the relevance of the regime-shift concept to tuna fisheries in the tropical western and central Pacific Ocean (WCPO; see Figure 1).

The management context was clear: it was uncertain whether recruitment predictions in tuna stock assessments were correctly capturing the effects of environmental variability or whether the results were erroneous due to the development of purse seine fisheries (capturing smaller fish) half-way through the time series.

Previous studies on ocean ecosystem regime shifts have focused on the northern Pacific Ocean (NPO) and on correlation between ocean-basin-scale indicators (i.e., the Southern Oscillation Index [SOI] and the Pacific Decadal Oscillation [PDO], Figure 2) and biological variables such as primary and secondary production, recruitment, and catch.

However the Pacific Ocean covers a very large area. There is no a priori reason why ecological events significant in one region should be duplicated in other regions half an ocean away. Furthermore the predominant mode of variability in the WCPO is interannual, based upon the El Niño Southern Oscillation (ENSO), while we were interested in decadal-scale variability and the existence of relatively stable states (i.e., regimes) with rapid transitions (i.e., shifts) between them.

Our project had three components: first, data rescue of historical datasets on tuna diet in the Pacific and comparison with data collected in recent years; second, objective characterization of oceanographic variability and derivation of oceanographic indicators; and third, development of statistical models relating oceanographic variability to tuna recruitment. The first two components seek to improve our ecological understanding while the third seeks to apply that knowledge to improving stock assessments and projections.

Tuna Diet Analysis

Diet data was obtained from a 1975 study by R. Grandperrin in New Caledonia and from the ECOTAP (Etude du Comportement

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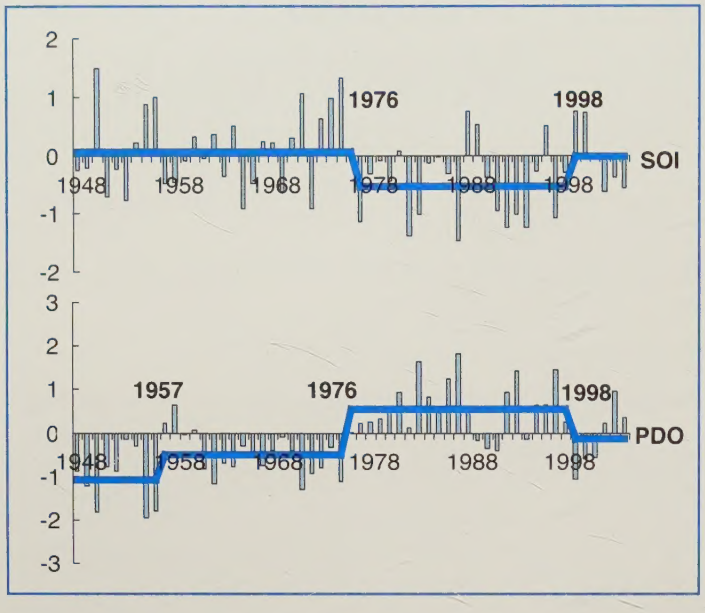

Figure 2. Time series for Southern Oscillation Index (SOI) and Pacific Decadal Oscillation (PDO) ocean-basin-scale indicators of atmospheric pressure and sea-surface temperature, respectively. Dates of statistically significant regime shifts are shown.

des Thonidés par l'Acoustique la Pêche en Polynésie Française—a study of tuna behavior by acoustics and fishing methods) project in French Polynesia, which took place in the mid 1990s (Frédéric Ménard and Arnaud Bertrand, personal communications). In both cases the historical data were compared with data collected by the Secretariat of the Pacific Community-Oceanic Fisheries Programme (SPC-OFP) in the last five years. This allowed for comparison of tuna diets in New Caledonia and French Polynesia both before and after the regime shifts posited for the mid/late-1970s and late-1990s, respectively.

Data analysis was complicated by the fact that experimental protocols differed among the studies. Also the taxonomic level to which samples can be identified depends upon both the skill of the technician and the availability of reference material. We realized that the finest scale of resolution was not necessarily the most informative. Comparisons made at the family level represented the best compromise between accuracy and precision.

Between the two studies in each area there was a decrease in fish-family diversity, a decrease in the abundance of the mesopelagic squid Ommastrephidae, an increase in epipelagic crustaceans, and other changes in the proportions of prey functional groups. However in both cases we had reservations that the changes were due to decadal rather than interannual variability. All studies took place over several years and comparison of these years with SOI showed that different ENSO phases had occurred during each study.

Models for Ocean Variability and Tuna Recruitment

Using ocean general circulation model (OGCM) output we explored a range of methods for time-series analysis and for linking long-term ocean variability to tuna recruitment. These included generalized additive models (GAMs), generalized linear models (GLMs), Fisher information, functional approximation, intervention analysis, and principal components analysis, also known as empirical orthogonal function analysis (PCA-EOF).

Initially we arbitrarily chose the spatial scale and areas for which to aggregate ocean variables prior to analysis, identifying areas approximating the full extent of the probable spawning grounds for tropical tunas. Subsequently we developed GLMs that selected the best areas, spatial scales, time lags and input variables as part of the model-building process in order to predict yellowfin tuna recruitment from ocean variables.

A single area defined by fifteen degrees of latitude and thirty-five degrees of longitude, located at the northern boundary of the western Pacific warm pool, was selected for the final GLM (Figure 1). Prediction was best with no time lag between predictor variables and the response in recruitment.

The GLM was developed for the period of 1980–2003, a period for which there is confidence in the recruitment estimates from the assessment model. The GLM accounted for 55% of the variance in yellowfin tuna recruitment estimated by the assessment model for this period. It was then hindcast to predict recruitment for the period 1948–1980. These predictions were compared with recruitment estimates from stock assessments.

From the 1960s onwards the GLM-predicted recruitment exhibits similar variability to the recruitment estimates from the assessment model (which was greatly improved for the 2007 assessment). The GLM captures the same interannual and decadal variability in recruitment but not the extreme peaks and troughs estimated by the assessment model.

GLM-predicted recruitment is much lower than estimates from the stock assessment for the period prior to the 1960s. The confidence limits for the predictions are very broad for this period, as oceanographic conditions are encountered which were not present during the model-building period. Nevertheless the recruitment predictions are closely related to warm pool area.

Warm Pool Area

The area and variables selected in the GLM were suggestive of oceanographic variability at the boundary of the western Pacific warm pool. We investigated the long-term variability of warm pool area and found that the area enclosed by the 28.5°C isotherm accounted for 71% of the variation in GLM-predicted recruitment for yellowfin. Decadal-scale variability was well captured, especially the regime shifts in both yellowfin recruitment and warm pool area in the 1960s (Figure 3). Warm pool area is therefore a very powerful and simple indicator of long-term variability in yellowfin tuna recruitment.

Regime-Shift Detection

Having developed the recruitment GLMs we then applied objective methods to detect statistically significant regime shifts in the OGCM output and in predicted recruitment. Our

preferred method for regime-shift detection was the "sequential *t*-test analysis of regime shifts" (STARS; see papers by S.N. Rodionov).

We examined the long-term variability of the oceanographic variables input to the GLMs using PCA-EOF, which reduces the dimensionality of a multivariate dataset to a series of uncorrelated principal components (PCs). Each PC accounts for a certain percentage of the total variance in the data. It is also possible to identify which variables are best described by which PCs. Those that capture a significant proportion of the variance in a range of ecosystem components may serve as ecosystem indicators. We then carried out STARS analysis on the PCs to detect shifts in these indicators.

Three significant PCs were identified (Figure 4):

- PC1 accounted for 35% of the temporal variance in the ocean data, with successive positive regime shifts in 1960, 1967, and 1997. This PC best describes temperature range and ocean currents.
- PC2 accounted for 20% of the temporal variance and best described wind strength and primary production. Alternately negative and positive regime shifts in PC2 occurred in 1958, 1968, 1988, and 1998; however, when a "pre-whitening" procedure that removes autocorrelation in the time series was applied the only shift detected was in 2002.
- PC3 accounted for 15% of the temporal variance. Turbulence was the strongest variable on this PC and regime shifts were detected in 1960 and 1999 only, the first shift being removed when the pre-whitening procedure was applied.

We then compared the timing of these shifts with the GLM-predicted recruitment series (Figure 3, regime shifts not shown). The recruitment series shows only one regime shift, which was in 1964. After that the series does vary but on quarterly and interannual rather than decadal scales.

Conclusions

The comparative analysis of tuna diet illustrates the need to discern the state of the environment during sampling periods. The results suggest that changes in tuna diet do occur and that these changes are probably reflective of changes in the species composition of the forage base. However we cannot say whether these changes occur on interannual or decadal scales.

The PCA-EOF and STARS analysis of ocean variables identify the principal modes of environmental variability in an area that is most important for tuna recruitment. Regime shifts are identified in the PCs but, apart from post-1998 events, these shifts do not appear to be as strong as or coincident with the shifts in SOI and PDO, for which ecosystem impacts have been documented in the North Pacific.

However the strong shift in warm pool area in the 1960s is coherent with shifts in recruitment and PC1. Assuming this is not an error in the OGCM, it represents the strongest regime shift in

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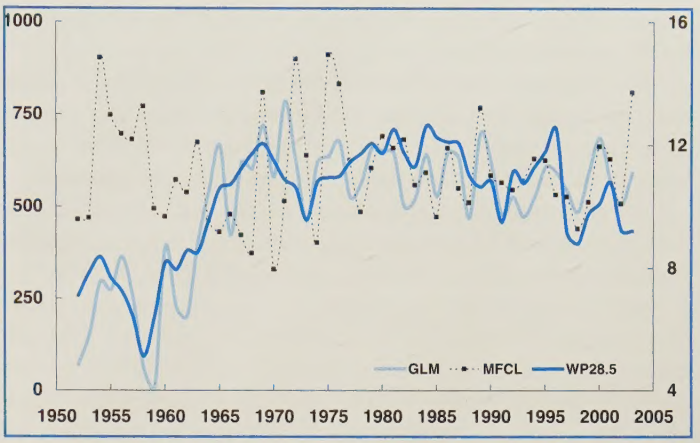

Figure 3. Yellowfin tuna recruitment estimates (first y-axis; units: millions of fish) from the stock assessment model MULTIFAN-CL (MFCL) and the generalized linear model (GLM) plotted with annual average warm pool area (WP28.5, second y-axis; units: millions of square kilometers).

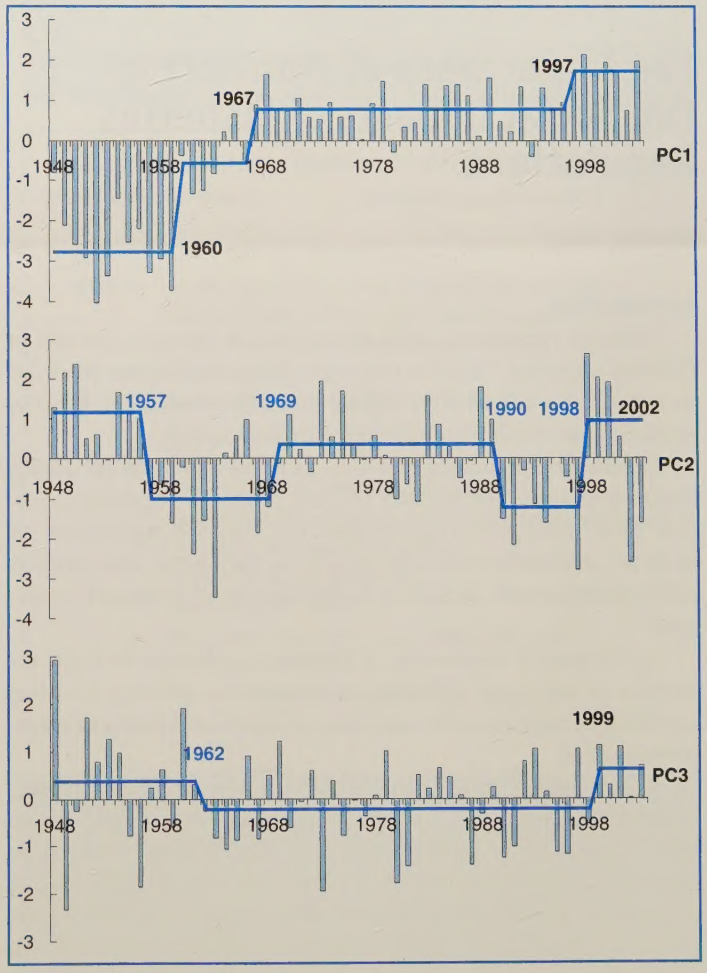

Figure 4. The three principal components (PCs) of temporal variability in ocean data selected by the GLM to predict yellowfin tuna recruitment. Dates of regime shifts are shown—those in blue were not statistically significant after "pre-whitening" of the time series.

Regime Shifts (continued from page 3)

ocean variables and yellowfin tuna recruitment thus far described for the western Pacific.

The hindcast GLM predictions can be used to constrain future assessments and the GLM can also be used to predict recruitment under present and future ocean conditions. This will be useful when stock projections are required for management purposes.

The environmental variability and regime shifts described here have implications for biological reference points based on equilibrium assumptions (e.g., Maximum Sustainable Yield [MSY]).

MSY calculated for the current recruitment regime may differ from that calculated under equilibrium recruitment. This will change the likelihood that overfishing is occurring during any particular regime. Further work by ourselves and colleagues (Mark Maunder, personal communication) will explore the utility of regime-specific and "dynamic" estimates of MSY.

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The Importance of Monitoring the Social Impacts of Fisheries Regulations

Stewart Allen

Introduction

Fisheries regulations are a critical tool in the management of fisheries resources. Fisheries managers design regulations intended to control the behavior of fishers to sustain and grow fisheries resources for which these managers are responsible.

Federal law mandates that U.S. fisheries managers are legally required to assess the impacts of their proposed regulations. Not only must managers gauge whether the intended regulations are likely to accomplish fisheries objectives, they must also estimate other consequences, including social impacts, of proposed regulations.

Social impact assessment of fisheries regulations includes the analysis of the likely influence of regulations, projects, or other regulatory activities on the daily lives of fishers and their associated communities.

Social impact assessment in fisheries management is particularly challenging in that it attempts to predict how fishers will respond to proposed regulations or possible alternatives. Individuals and communities are often remarkably adaptable in successfully identifying responses to new regulatory restrictions (Interorganizational Committee on Principles and Guidelines for Social Impact Assessment 2003). However some fishers, fishing households, fleets, or communities may be less resilient than others to the social impacts of such regulations. Our study considered various reasons for differences in resiliency.

Monitoring

To assess the extent to which both intended and unintended consequences are generated by new fisheries regulations, one must directly monitor the affected populations. Pre-regulation impact assessment can only estimate the likely effects. Monitoring is needed to reveal the short- and long-term impacts of regulations on both individual fishers and specific industry segments. Such information can then be used to adapt subsequent management efforts.

A study conducted on one segment of longline fishers affected by the 2001 closure of the Hawai'i-based swordfish fishery demonstrates the critical significance of monitoring designed to compare predicted with actual social impacts. Societal responses of these longline fishers were analyzed to assess changes occurring from the 2001 swordfish fishery closure through and beyond the 2004 fishery reopening. Much was learned regarding how these fishers adapted to the closure and the reopening of the swordfish fishery. Details of this study were previously published in the peer-reviewed journal *Human Organization* (Allen and Gough 2006).

Background—The Hawai'i-based longline fishery lands the vast majority of the Hawai'i commercial pelagic catch. Of the 120 vessels active in 2001, about 40 were owned by Vietnamese-American fishers (nearly all of the rest were owned either by Korean-American or by Euro-American fishers). Since the late 1980s nearly all of the Vietnamese-American longline fishers had targeted swordfish, the largest component of the longline catch in 2000.

This situation changed dramatically following court-ordered regulations resulting from a 1999 lawsuit against the National Marine Fisheries Service (NMFS). A final environmental impact statement (FEIS) for Hawai'i pelagic fisheries published March 30, 2001 (implemented in 2002), contained measures that essentially closed the Hawai'i-based longline swordfish fishery (National Marine Fisheries Service 2001).

The FEIS included a social impact assessment which predicted that the swordfish closure and related actions would disproportionately and negatively affect Vietnamese-American fishers, posing environmental justice issues.

President Clinton's Executive Order 12898 (issued February 11, 1994; amended January 30, 1995) on environmental justice issues had earlier required that: "Each federal agency shall make achieving environmental justice part of its mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority populations and low income population."

The FEIS described the effects of the court ruling on vessel owners as "immediate and substantial" as well as imposing "severe economic hardship" on owners and crew members of Vietnamese-American descent. The FEIS economic analyses predicted substantial declines in: the number of vessels that would break even; fishery gross revenues; direct payments to labor; purchases from local suppliers; and total economic impact. The FEIS suggested that effects on owners could be mitigated by permit or vessel buyback programs (which were not developed).

Given a lack of data specific to longline fishers, the FEIS cited a previous study of workers on the island of Hawai'i laid off from the sugar industry to describe the range of possible social impacts. These include sustained unemployment and loss of income and resulting social and psychological impacts such as heightened feelings of anxiety, depression, illness, and increased problems in relationships among laid-off employees and family members.

Methods

To monitor the actual effects of the longline swordfishing closure on Vietnamese-American fishers, households, and community, between June and November 2003 we conducted a series of forty in-depth oral histories with Vietnamese-American longline vessel owners, captains, crew, and spouses. The forty individuals interviewed represented a broad cross-section of the Vietnamese-American sector of the Hawai'i longline fleet.

Sampling began with a core group of well-known fishers and progressed on an opportunistic basis until about 75 percent of the Hawai'i-based Vietnamese-American longline vessels had been represented by at least one individual.

As many fishers spoke little or no English or were uncomfortable communicating in English, all interviews were conducted with the assistance of a Vietnamese interpreter. Not surprisingly, even fishers and spouses who had a conversational-to-fluent command of English could communicate some sentiments more effectively in their native language.

The interpreter also functioned as a community liaison whose presence and expressed interest in the fishers helped create a more comfortable atmosphere even when interpretation was not required. The interpreter/community liaison played an extremely

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UPCOMING EVENTS

PFRP Principal Investigators Workshop

November 13–15, 2007, Honolulu, Hawai'i
Contact: John Sibert <sibert@hawaii.edu>
http://imina.soest.hawaii.edu/PFRP/

GLOBEC-CLIOTOP, 1st CLIOTOP Symposium

December 3–7, 2007, La Paz, Mexico
Contacts: Olivier Maury <Olivier.Maury@ird.fr> or Patrick Lehodey <Plehodey@cls.fr>
https://www.confmanager.com/main.cfm?cid=722

Advances in Tagging and Marking Technologies for Fisheries Management and Research

February 24–28, 2008, Auckland, New Zealand
http://www.fisheries.org/units/tag2008/index.html

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Erratum

Page 6 of the July–September 2007 *PFRP Newsletter,* 12 (2), contains an error in the second line of the caption of Figure 4. The correct caption should read "Typical pattern for the second tracking of time-series swimming depth of the fish around FAD, noting isotherms. Black bars show nighttime and the legend shows species, pinger number, and length of the fish."

valuable role because fishers and family members were being asked to speak openly about deeply personal and emotional topics.

Results

The longline swordfishing closure was a precipitous event to all of those interviewed. These Vietnamese-American fishers and their families had moved to Hawai'i, which they viewed as a highly desirable location, to specialize in a fishery that was now suddenly unavailable.

There are many ways the types of impacts described by the fishers might have been categorized. The effects of the fishing ban generated a complex web of social and economic factors. Our study chose to identify impacts on income, psychological well-being, family cohesion, community cohesion, and cumulative impacts. While these categories overlap they serve to capture a broad range of effects and to document their interrelationships.

Impacts on Income—Prior to the ban, swordfishing had been a lucrative business.

Our study did not measure household income before or after the closure of the swordfish fishery nor quantitatively assess other economic impacts. However the interviews made it clear that decreased income was a major concern within the Vietnamese-American fishing community.

Two-thirds of the owners and an even higher proportion of captains described their current (post-closure) level of income as very much of a problem. This was significant because two-thirds of the owners and crew and over three-quarters of the captains said that longline fishing provided all of their family's income.

Following the ban, some owners kept their vessels in Hawai'i and converted to tuna fishing while some relocated their vessels to California where they could continue to fish for swordfish (until that fishery closed in 2004).

Swordfishing vessel owners who kept their boats in Honolulu and converted them for tuna fishing received $32,000 per vessel through a federal economic assistance program. This amount was based on an estimated cost of the new fishing gear needed to convert a swordfishing boat to fish for tuna but included no funds to cover labor costs to install this gear.

Also problematic was the timing of these payments. In many cases the funds were not available before fishers converted their boats. In such circumstances the conversion costs added to the boat-owner's overall debt. When they actually received payments owners sometimes faced more immediate financial needs for the funds so the conversion debts remained outstanding. And, while the economic assistance program provided some funds for vessel owners, this program did nothing to benefit Vietnamese-American captains or crew members.

Impacts on Psychological Well-Being—Most of the owners and captains were able to find a way to continue fishing. This was not accomplished, however, without significant psychological cost.

Interviewees expressed a range of emotions: bewilderment at the closure and its reported justification; loss of confidence that their family would be adequately cared for; shame at not being able to help family members living with them or elsewhere; sadness at the decrease in their quality of life; anger at the federal government for closing the fishery; anger at entities both inside and outside the fishing industry for their perceived inability to prevent or reduce effects of the ban; exasperation that only the American fleet and not the international fleet was being regulated; and frustration at being unable to thwart the ban legally or politically and at being forced to rely, unsuccessfully, on others. Some interviewees indicated a sense of hopelessness due to their inability to influence the ban.

Many expressed concern with the swordfish closure in terms of its impact on the quality of their life. Lifestyle priorities for fishers included not only the ability to sustain their fishing lifestyle but to do so in Hawai'i, a place they had come to love. Interviewees expressed a preference for living in Hawai'i compared to locations on the Gulf of Mexico and other places they had lived while participating in other fisheries.

Many cited enjoying living in Hawai'i because of its climate, social diversity and tolerance, schools, year-round fishing opportunities, availability of preferred food, presence of an active Vietnamese-American community, income potential from fishing, and "the spirit of aloha."

Vietnamese-American fishers had many motivations for fishing beyond earning an income. Just one-quarter of the owners and one-third of the crew said they considered fishing only as a way to make money and not as a way meet other needs, although a higher proportion of captains (four of the six interviewed) viewed fishing primarily as a source of income. Some interviewees simply said "Fishing is what I do; I don't know anything else."

Impacts on Family Cohesion—Interviewees reported many negative effects generated by the ban on the closeness and cohesion of their families and on their ability to meet family needs. One wife said that the ban had increased the pressure and stress in the family due to constant worrying about financial problems, leading to an increased number of arguments.

Less time and money were available for regular visits to relatives living elsewhere in the U.S. or in Vietnam, thus exacerbating the emotional separation among extended families. Some families curtailed or eliminated financial assistance to parents, extended family members living in their vicinity, or family members living in Vietnam or elsewhere outside of Hawai'i.

Fishers who relocated with their vessels to California were away from home for much longer periods of time than previously. Many of their wives then also traveled to California for a week or more each month to help between fishing trips, further fracturing established patterns of family behavior.

Vietnamese-American fishers interviewed were very concerned about the effects on their children of the longer periods of separation from their parents as well as from the lowered quality of life and other financial impacts. Of the boat owners, almost half had four or more children and many had additional dependent family members in Vietnam or elsewhere for whom they had previously provided financial support.

Interviewees reported that the ban had a significant impact on their children's education, which was highly valued. Nearly all of the interviewees spoke about wanting their children to have quality educations so that they would not have to fish for a living.

Impacts on Community Cohesion—The primary community considered in this research was the Hawai'i-based Vietnamese-American longline fishing community. This community was described by participants as a tightly knit group of people who could expect to borrow money from each other and help each other out in many ways.

Nearly all of the fishers interviewed described a network of people with whom they shared information. They reported they had someone in their industry to whom they could turn if they needed help.

Money, as well as information, had been shared. Many examples of no-interest loans made on an informal basis were described during the interviews. If times were rough for one family, another that was doing better would help them out and not expect repayment until the troubled family recovered. These transactions became less frequent because there was less money to spread around.

The strong sense of community had been a source of resiliency for this group of fishers and their families. However fishers generally expressed that the swordfish closure had lowered cohesion among the Vietnamese-American fishing community. According to several interviewees, the community generally became very discouraged at the decision to close the fishery: "Group morale is very low because income is down and there are [only] uphill battles with no victory."

Fewer community social events, such as the prior celebrations of swordfish boats returning to port, were organized. The Hawai'i-based Vietnamese-American fishing community further fragmented when some boats relocated to California, where no comparable Vietnamese-American fishing community was to be found.

Cumulative Impacts—The effects of the swordfish fishery closure were compounded by the concurrent impact of other regulations and trends affecting the longline fishing industry.

As Hawai'i-based Vietnamese-American fishers left the fleet for land-based jobs, boat owners needed, and found, alternate sources for crew. Most of these replacement fishers came from the Philippines.

However the events of September 11, 2001, and following federal responses made it more difficult and more costly to bring foreign crew into the U.S.

Other fishing regulations or closures limited fishers' ability to adapt by switching to alternative fisheries. Prohibition of shark finning eliminated a once-substantial secondary source of income for captains and crew. Fuel prices increased significantly, adding yet another barrier to profitable fishing.

Study Conclusions

Interpreting the magnitude and meaning of impacts resulting from the swordfish ban—or other types of change—depends in part on the resiliency of the affected population (Hanna and Hall-Arber 2000).

Some of the Vietnamese-American fishing households were more resilient than others because they had alternative sources of income. Some also had the ability to relocate their vessels to California—although that turned out to be only a short-term solution. Another factor positively contributing to resiliency was the experience of having successfully adapted to changing conditions in the past. On average, the Vietnamese-American owners and captains interviewed had worked in three other fisheries before successfully adapting to swordfishing in Hawai'i.

Such sources of resiliency allowed fishers to adapt to the closure to varied extents. As one fisher said, "At first we were devastated. After the ban, my job satisfaction went from a 'ten' to a 'one.' Now we've been learning and coping, so maybe I'm at 'five' now."

Most of the affected fishers did what they believed was needed to survive their immediate difficulties with the hope and belief that the Hawai'i-based swordfish fishery would someday be reopened. In 2004, based on newly designed fishing gear and techniques reducing sea turtle interactions, that happened. NMFS re-opened the swordfish fishery, capping the amount of fishing effort allowed at 2,120 sets and terminating fishing sooner if a certain number of sea turtles were caught. NMFS also required that all vessels targeting swordfish carry scientific observers and abide by certain restrictions on fishing gear.

Yet when the swordfishing opportunity returned in 2004 there was not an immediate rush to participate. Having converted their boats and spent considerable time learning to fish for tuna, some Hawai'i-based Vietnamese-American fishers were reluctant to resume swordfishing. Many were not happy with the gear requirements that accompanied the fishery's re-opening. They were also unhappy with the new NMFS method of allocating the swordfish sets, offering them to anyone having a longline fishing permit who expressed interest in joining the swordfish fishery—whether or not they had ever before fished for swordfish.

In 2005 more vessels went out to target swordfish. By the end of the calendar year the cap on sea turtles had not been reached despite fishers using most of the available swordfish sets.

In 2006, however, the annual cap on sea turtle interactions was reached in March, closing the swordfish fishery for the rest of the year. Because of this, all of the swordfish vessels out fishing then had to return to port at the same time and unload their catch, creating a temporary glut of swordfish and a correspondingly steep drop in price.

How has the situation changed in 2007? Vietnamese-American participation in the Hawai'i-based longline fishery has actually increased. One owner estimated there are now fifty-five to fifty-seven Vietnamese-American-owned vessels in the fleet, up considerably from pre-ban levels. About thirty of these vessels now fish exclusively for tuna while the rest primarily fish for swordfish and switch to tuna if the turtle catch limit is reached or when fishing for tuna becomes more profitable during the year.

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Importance of Monitoring (continued from page 7)

The Vietnamese-American longline fisheries sector has demonstrated its resiliency—although not without paying a painful price. The effects of the regulatory shift still linger today.

In summary, social and economic monitoring should be a key aspect of natural resource management planning and management. The initial estimation of impacts correctly predicted some types of effects but missed others completely, such as family- and community-level impacts.

As demonstrated by this case study, there is a clear need to track the dynamic and complex social consequences of regulatory change (Allen et al. 1998; Hall-Arber et al. 2001) and incorporate a mechanism for feeding that information back into an adaptive management framework.

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